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Widely and continuously tuneable liquid crystal lasers

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Abstract: Liquid crystal lasers offer wide, continuous tuneability across the visible and near-infrared (450–850 nm). Compared to conventional tuneable laser technology, liquid crystal lasers are highly compact and have simple and scalable manufacturability. Their ability to emit multiple simultaneous emissions of arbitrarily selectable wavelength also gives them functional advantages over competing technologies. This paper describes Förster transfer techniques that have enabled this extended continuously tunable emission range, whilst maintaining a common pump source.

OCIS codes: (140.3460) Lasers; (160.3710) Liquid crystals

1. Introduction to band-edge liquid crystal lasers

Conventional continuously tuneable laser technologies, such as dye lasers, optical parametric oscillators or Ti:Sapphire lasers, are generally large, complex and highly expensive systems. They often require considerable supportive infrastructure, such as water-cooling or high-voltage electrical supplies, and their operation is limited to trained personnel within dedicated laboratories. This limits their commercial applicability, despite their functional advantages over fixed-wavelength systems. A simple, compact and affordable tuneable laser system would have far-reaching commercial applications, enabling the wider adoption of tuneable lasers to optical tools such as fluorescence microscopy and spectroscopy. Liquid crystal (LC) laser technology [1] enables such simple, compact and affordable tuneable coherent sources to be realized. Recent developments include: high-efficiency (up to 60 %) and low threshold systems [2]; array-based pumping for high-power throughputs [3]; simultaneous polychromatic emissions [4]; and the printing of individually addressable lasers onto arbitrary surfaces [5]. Continued development of low-cost and compact pump sources such as laser diodes or LEDs mean that hand-held devices incorporating tuneable lasers may soon become a reality, with far-reaching applications in areas such as point-of-care optical medical diagnosis. With further progress extending the tuning range into the near-infrared (NIR), new applications in areas such as local area network optical telecommunications, or sub-dermal imaging with optical coherence tomography, may also soon become realizable.

Lasing in dye-doped LCs was first experimentally observed by Kopp *et al.* [6]. Chiral nematic LCs spontaneously form a helical molecular configuration. The optically anisotropic nature of the LC means that this self-assembled twisted microstructure has a periodic refractive index, and thus forms a one-dimensional photonic band-gap. Circularly polarized light is therefore selectively reflected from the structure and can provide distributed feedback for mirrorless lasing within a resonant cavity only 10–20 μm thick. A gain medium in the form of an organic dye is then doped into the LC, such that the fluorescence maximum overlaps the reflection band of the LC. When optically pumped close to the absorption maximum of the dye, stimulated emission occurs, preferentially at one of the band-edges of the system, where the density of photonic states is a maximum.

Wavelength tuning of band-edge lasers can be achieved by modifying the chiral pitch of the liquid crystal. The simplest mechanism for this is variation of the chiral dopant concentration. Electrical tuning is also possible [7, 8], although a simpler solution is to use gradient-pitch cells, enabling tuning through translation of the cell relative to the pump beam [4, 9]. So far, continual tuning across the visible spectrum from blue to red has been successfully achieved using this method (pumped at 430 nm). This paper describes the extension of this tuning range into the NIR. Unfortunately, NIR-emitting dyes such as LD800, HITC-P and DOTC-P, which have been previously demonstrated to lase in the range of 735–850 nm [10], do not share common absorbance at 430 nm, and must instead be excited around 690 nm. However, the red-emitting dye DCM has a fluorescence spectrum that overlaps with these NIR dye absorbances (Fig. 1), and lasing should be possible via Förster energy transfer between the dyes.

3. Experiment and results

An equimolar mixture of the dyes DCM and LD800 (Exciton), at a total concentration of 2 % w/w in the nematic liquid crystal BL006 (Merck) was prepared. A further 3 % w/w of the high-twisting power chiral dopant BDH1281 (Merck) was also added, to provide a long photonic band-edge at around 800 nm, previously found to be the most efficient position for lasing in LD800 [10]. The mixture was filled into 10 μm thickness glass cells, coated with antiparallel-rubbed alignment layers to induce the Grandjean (standing helix) LC texture. Optical excitation was provided by a Nd:YAG frequency-tripled (355 nm) laser (Spitlight, Innolas) connected to an Optical Parametric

Oscillator (OPO) (GWU), tuned to 430 nm, generating 5 ns pulses at a repetition rate of 2 Hz, focused to a spot 300 μm diameter. As Fig. 1 shows, at this 430 nm excitation, only the DCM absorbs the light. The corresponding red fluorescence overlaps with the absorbance of the LD800, and is thus reabsorbed by the system. This enables successful lasing to occur from the LD800 at 800 nm, where the chiral pitch provides resonance.

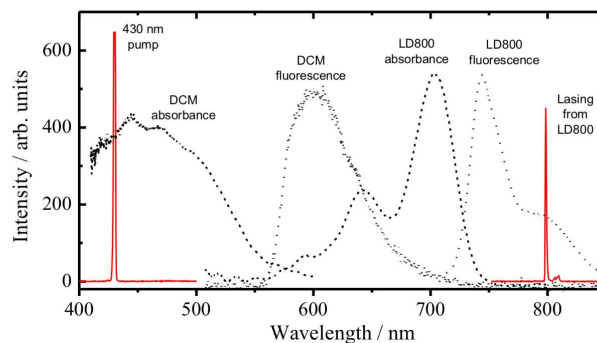


Fig. 1. Förster energy transfer of a doubly dye-doped LC band-edge laser enables emission to occur in the NIR from LD800, when pumped at the absorbance of DCM.

It should be noted that lasing here is not limited to 430 nm pump wavelengths exclusively, but has also been achieved elsewhere within the absorbance band of DCM (e.g. at 532 nm from a frequency-doubled Nd:YAG). Furthermore, by varying chiral dopant concentrations, Förster transfer NIR emissions at other wavelengths are possible, ranging from approximately 700–850 nm, and are shown in Fig. 2. The graph also shows typical visible laser lines from the dyes C504, C540A, PM590 and DCM, pumped directly at 430 nm. It therefore illustrates the full spectral range currently achievable by LC lasers, from 450–850 nm, whilst pumped with a common pump source.

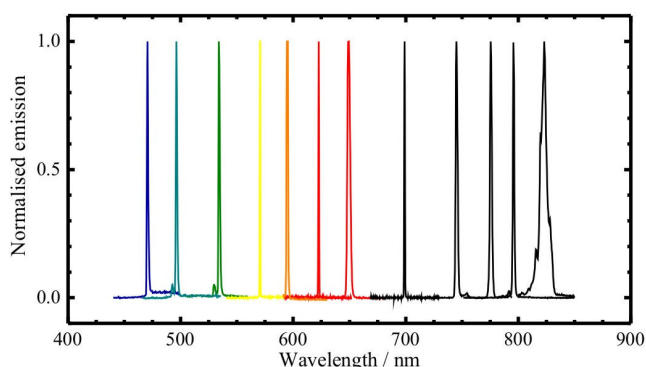


Fig. 2. Available range of continuously tuneable emission spectra from LC lasers.

3. Conclusion

These results demonstrate that continuously tuneable gradient-pitch tuneable liquid crystal lasers can be achieved, widely emitting across the visible and NIR, whilst pumped with a single excitation source. Fig. 1 also indicates that lasing is likely to occur when pumped at wavelengths around 405 nm. With the ongoing development of affordable laser diodes in this wavelength region, it is entirely feasible that highly compact and low-cost visible to NIR tuneable lasers can be achieved. We acknowledge the EPSRC for the COSMOS technology translation grant.

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